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Algorithms for Radio Networks

Multiplexing

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Multiple Use of the Medium

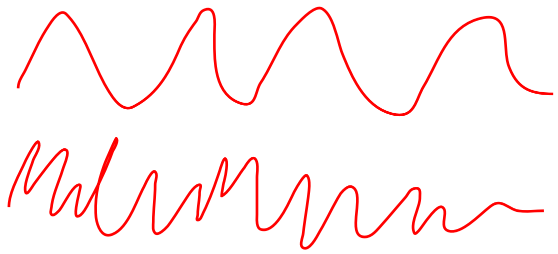
- **Spatial Multiplexing**
  - Parallel and exclusive use of transmission channels
    - e.g. Extra lines / cells / directional antenna
- **Frequency division multiplexing**
  - Multiple signals to be transmitted in a frequency range of bundled;
  - In radio transmission, different frequencies are assigned to different stations.
- **Time division multiplexing**
  - Delayed transmission of multiple signals
- **Code division multiplexing**
  - Coding of the signal into orthogonal codes, which can now be broadcast simultaneously on one frequency
  - Decoding with overlay also possible
- **Multiple-Input Multiple-Output**
  - Sending and receiving antennas by several
  - Using the spatial and temporal information about location of several waves
    - e.g. 802.11n

Space

- **Spatial distribution (space multiplexing)**
  - Utilization of distance loss for the parallel operation of different radio cells → cellular networks
  - Using directional antennas for communications directed requested
  - GSM antennas with directional characteristics
  - Radio with a satellite dish
  - laser communications
  - infrared communication

Frequency Multiplexing

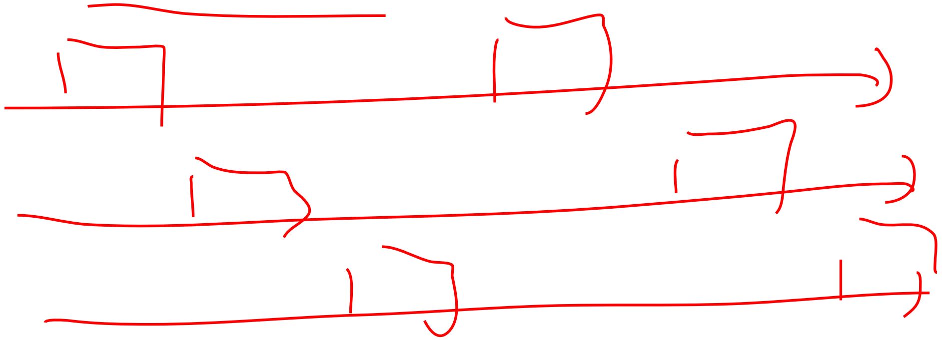
- **Allocation of bandwidth in frequency sections**
- **Spread of the channels and hopping**
  - Direct Sequence Spread Spectrum (DSSS)
  - Xor a signal with a pseudo-random number sequence at the transmitter and receiver (Relates to code-division multiplexing)
  - Other signals appear as background noise
- **Frequency Hopping Spread Spectrum (FHSS)** Bluetooth
  - Frequency change by pseudo-random numbers
  - two versions
    - Quick change (almost hopping): Multiple frequencies per user data bits
    - Slowly changing (slow hopping): Multiple user bits per frequency



Time Multiplexing

- Temporal distribution of sender-/receiver channel
- Participants receive exclusive periods (slots) on the media
- Accurate synchronization necessary
- Coordination necessary, or rigid division

TDMA → MAC



Direct Sequence Spread Spectrum

- A chip is a bit sequence (given by {-1, +1}), which encode a smaller set of symbols
- E.g. Transmission signal: 0 = (+1,+1,-1), 1=(-1,-1,+1)

0	1	0	1
+1 +1 -1	-1 -1 +1	+1 +1 -1	-1 -1 +1

- Coding by calculating the inner product $c_i\, s_i$ of the received signal and the chip $c_0 = - c_1$:

$$\sum_{i=1}^{m} c_{0,i} s_i \qquad \sum_{i=1}^{m} c_{1,i} s_i$$

- In the case of a superimposed signal, the original signal can be decoded by filter
- DSSS is used by GPS, WLAN, UMTS, ZigBee, Wireless USB based on the Barker code
  - Here for all v<m

$$\left| \sum_{i=1}^{N-v} a_i a_{i+v} \right| \leq 1$$

- Barker Code für 11Bit: +1 +1 +1 –1 –1 –1 +1 –1 –1 +1 –1

+1 +1 +1 -1 -1 -1 +1 -1 -1 +1 -1

= 0

+1 +1 -1 (S)

-1 -1 +1 (1)

-1 + -1 + -1 = -3

S: -1 +1 +1

1: -1 -1 +1

= +1 + (-1) + +1

Code Division Multiple Access (CDMA)

- **CDMA (Code Division Multiple Access)**
  - e.g. GSM (Global System for Mobile Communication)
  - or UMTS (Universal Mobile Telecommunications System)
- **Uses chip-sequence with**
  - $C_i \in \{-1,+1\}^m$ 0
  - $-C_i = (-C_{i,1}, -C_{i,2}, \ldots, -C_{i,m})$ 1
- **so that the normalized inner product for all i ≠ j the result is 0.**

$$C_i \bullet C_j = \frac{1}{m} C_i \cdot (C_j)^T = \frac{1}{m} \sum_{k=1}^{m} C_{i,k} C_{j,k} = 0 \ .$$

- **Synchronized recipients get a linear combination of A and B**
- **Multiplying by the desired chip sequence yields the desired message.**

Code 1

0 : −1 −1 +1 +1

1 : +1 +1 −1 −1

Code 2

0 $\boxed{-1 \ +1 \ +1 \ -1}$

1 +1 −1 −1 +1

−1 −1 +1 +1

−1 +1 +1 −1

\+ − + −

Σ : 0

CDMA: Example 1

- **Sender A:**
  - 0 = (-1,-1)
  - 1 = (+1,+1)
- **Sender B:**
  - 0 = (-1,+1)
  - 1 = (+1,-1)
- **A sends 0, B sends 0:**
  - Result: (-2,0)
- **C receives (-2,0):**
  - Decoding of A: (-2,0) • (-1,-1) = (-2)(-1) + 0(-1) = 2
  - A has therefor sent 0 because result is positive

A -1 -1
B -1 +1
(-2, 0)

A 2 0
-1 -1 ← 0
2 + 0 = 2

B -2 0
-1 +1 ← 0
2 0 = 2

A: +10 +10
B: -1 +1
9 11

9 11
-1 -1 0
-9 + -11 = -20 -> 1

9 11
-1 +1 0
-9 11 = 2

CDMA: Example 2

- **Sample-code:**
  - Code C_A = (+1,+1,+1,+1)
  - Code C_B = (+1,+1,-1,-1)
  - Code C_C = (+1,-1,+1,-1)
- **A sends Bit 0, B sends Bit 1, C sends nothing**
  - $V = C_1 + (-C_2) = (0,0,2,2)$
- **Decoding for A: $V \bullet C_1 = (0,0,2,2) \bullet (+1,+1,+1,+1) = 4/4 = 1$**
  - results in Bit 0
- **Decoding for B: $V \bullet C_2 = (0,0,2,2) \bullet (+1,+1,-1,-1) = -4/4 = -1$**
  - results in Bit 1
- **Decoding for C: $V \bullet C_3 = (0,0,2,2) \bullet (+1,-1,+1,-1) = 0$**
  - results in: no Signal.

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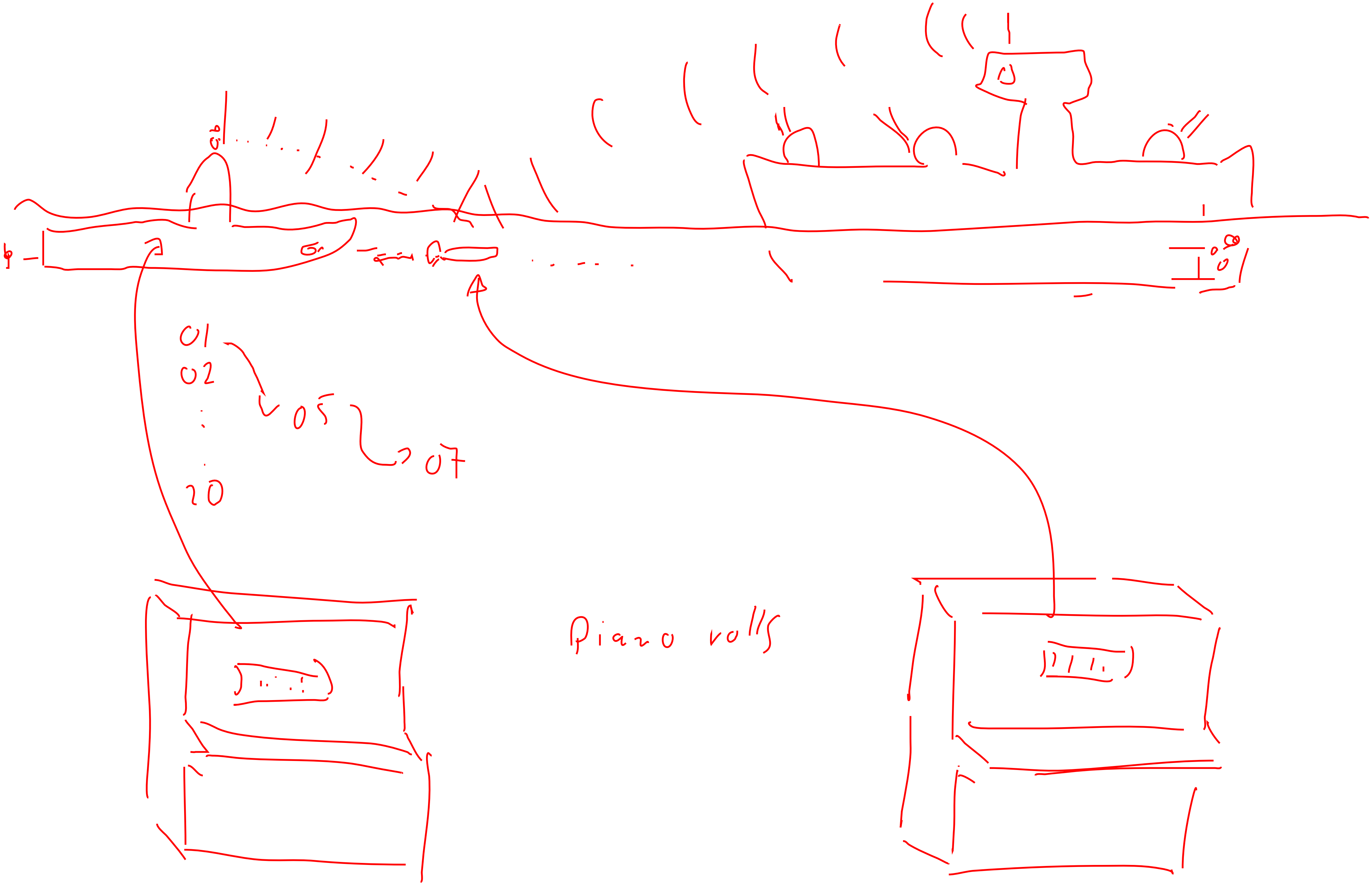
01
02
05
07
20
piano rolls

$$a_1 + a_1 \cdot a_2 + a_2 \cdot a_3 + \ldots$$